Experiment No. 6
Transmission Lines and Time Domain Reflectometry

Complete Experiment No. 6 Pre-Lab Before Beginning Experiment

Include all measured data in a report to your lab instructor. The report is a discussion of your results following the guidelines given at the end of the experiment. You may add additional comments as desired. Be sure to discuss how your results differed from the results you expected from the pre-lab.

Part A: Reflections on a Transmission Line

Objective: To observe the effect of reflections on a transmission line

1) Use a BNC T-connector and a short BNC to BNC cable to connect the function generator to Ch1 of the oscilloscope. Connect a long coaxial cable to the other end of the T connector. Set the function generator to produce a 0 to 5V square wave at 1 MHz. Be careful when setting the function generator voltage that you don't misinterpret the internal meter reading which will be in error unless the generator is set to the high-Z mode.

Note: The function generator has a 50Ω source impedance. If it is set to the high-Z mode the instrument will read correctly for the open circuit condition and when it is set for the 50Ω mode it will read correctly when a 50Ω load is connected. The generator internal meter does not measure the actual voltage at the output terminal. If you use the internal meter to set the voltage using the 50Ω mode instead of the high-Z mode you would get twice the meter reading in the open circuit condition. It is always good practice to verify the generator voltage with an external instrument such as the oscilloscope. If an external instrument is used to adjust the generator voltage, it doesn't matter whether the high-Z or 50Ω mode setting is selected as long as you ignore the internal meter reading.

2) Using the specifications for capacitance and inductance previously given, calculate the characteristic impedance of the cable. Connect a resistor, as close in value to the characteristic impedance as possible, to the end of the long cable. Connect the second channel of the oscilloscope to the resistor. Be sure to connect the scope’s ground to the cable’s shielding.

3) Observe the waveforms on both channels, triggering on the leading edge of Ch1. You should see a 0 – 2.5 V square wave on both channels with the output waveform lagging the input by an amount determined by the length of the cable. Using the shortest oscilloscope time base setting, measure the time difference between the leading edges.
4) Record the time-separation between the waveforms and calculate the length of the cable using this time measurement and the propagation velocity of the cable as determined by the distributed values of capacitance and inductance.

5) Remove the resistor from the end of the cable and observe both waveforms again. This time you should see that both signals have doubled in size. However, it takes twice the travel time at the source end for this to happen because now there is a reflected wave that has to travel back to the source end. You will see the same time difference between leading edges of the two waveforms, but the source end will double in size when the reflection reaches the source.

6) Verify that you see the effect of the reflected wave at the source end and measure the two way travel time by observing Ch1 and measuring the time from the beginning of the first plateau to when it fully reaches its maximum value.

7) Repeat the last observation, this time with the load end shorted instead of open. Both waveforms should be at zero volts except that a short pulse appears on the source end of the cable. Re-measure the two-way travel time by measuring the length of the pulse.

**Part B: Simulating a TDR**

Objective: To use an oscilloscope to verify the operation of a TDR

1) Disconnect the oscilloscope from Ch2 so that the load end of the line is not being viewed. Connect a 100 $\Omega$ resistor to the load end of the cable and observe the Ch1 waveform. Measure the two way travel time, and determine the length of the cable from the travel time. Sketch the Ch1 waveform.

2) Replace the 100 $\Omega$ resistor with a 25 $\Omega$ load resistor and sketch the waveform.

3) Physically measure the length of the cable by using a tape measure with the cable lying on the floor.

**Part C: SWR Measurements**

Objective: To investigate standing waves and electrical length on a transmission line

1) Change the function generator to produce a sine function at 5 V p-p and 1 kHz. Connect the generator to the transmission line, as you did in Part B. While viewing the waveform at the source end of the line, connect a 100 $\Omega$ load resistor to the other end of the line. Adjust the oscilloscope so at least one period of the input waveform is visible. Record the peak-to-peak source-end voltage. Compare this value to the value you expect based on the specified 50 $\Omega$ output impedance of the function generator using the voltage divider formula. It should be about 2/3 of the open circuit voltage value.
2) Calculate the electrical length of the transmission line at this frequency. Note that the line is electrically short at this frequency so that the impedance at the source end of the cable is the load resistance value of 100 Ω.

3) Increase the function generator frequency while observing any changes in the source voltage until you reach the largest frequency available (15 MHz).

4) Repeat both the previous steps with the load resistance of 10 Ω.

5) For each of the load resistors, calculate the electrical length of the transmission line at the frequency where you first noticed a 10% change in voltage. This may be different in each of the two load conditions. This is the frequency where we consider this line electrically long and transmission line theory becomes important to consider.

6) With the 10 Ω load, find the lowest frequency where the source voltage is a maximum. Note this voltage. Determine the electrical length of the line at this frequency?

7) At the frequency where the source voltage is a maximum, calculate the expected source voltage using a Smith chart to determine the expected impedance at the source end of the cable. Use the voltage divider formula and the 50 Ω generator impedance as before.

Submit a discussion of results to your lab instructor following the guidelines below. Include all measured data. Be sure to discuss how your results differed from the results expected from the pre-lab.

Part A:

Discuss the appearance of the source end voltage when the line is not terminated in $Z_0$ and differences for loads both larger and smaller than $Z_0$.

Comment on how conditions at various locations along the transmission line are determined by observations at the source end.

Part B:

Discuss the differences between sketches of the voltage at the source when the load impedance is changed and whether these differences can be used to tell anything about the loads.

Discuss the physical measurement of cable length and its relationship to the simulated TDR measurement.

Part C:
Discuss how changing the frequency of the source was able to provide information about standing waves on the line and the role of the Smith chart in interpreting that information.